ORIGINS OF PALLASITES AT THE CORE-MANTLE BOUNDARIES OF ASTEROIDS; Edward R.D. Scott and G. Jeffrey Taylor, Institute of Meteoritics, Dept. of Geology, University of New Mexico, Albuquerque, NM 87131

Although pallasites are mineralogically very simple igneous rocks, petrologists have proposed an extraordinary variety of origins including nebular condensation [1], crystallization of impact melts [2], and crystallization near the surface of an externally heated asteroid [3]. However, we and most workers believe that pallasites formed at the core-mantle boundaries of igneously differentiated asteroids [4-6]. Buseck [4] and Wood [6] emphasized the well-ordered features of certain pallasites: nearly close packed arrays of uniform sized, rounded, droplet-like olivine crystals in metallic Fe,Ni. They concluded that the olivines are cumulate crystals that formed by crystallization or partial melting, and that the intercumulus silicate liquid between the olivines was gently replaced by molten metal from the underlying core. By contrast, Scott [5] emphasized the disordered features of many pallasites: angular olivine fragments and polycrystalline olivine masses of various sizes mixed with highly diverse proportions of metal. He concluded that pallasites formed when fragments of olivine mantle were violently mixed with molten metal that solidified rapidly. Pallasites with rounded olivines, according to Scott [5], formed by metamorphism of angular olivine fragments after the metal crystallized. We conclude that some pallasites, those with large, rounded olivines, formed when cumulate crystals were submerged in the core by buoyancy forces, as Wood [6] proposed. But most pallasites, which have angular olivines, were formed by mixing of fragments of olivine mantle with molten metal [5] during impacts. Thus both equilibrium and non-equilibrium processes mixed olivine and molten metal.

Rounded-olivine pallasites. Olivine crystals from the mantle will be submerged in the core until their weight is supported by the upthrust of the displaced molten metal (Archimedes' principle) [7]. However, Wood [6] found that significant volumes of this pallasitic layer would be destroyed in large bodies (>15 km radius) when large stresses squeezed the metal from between the olivine crystals. This stress aided by adcumulus growth formed an olivine mantle above the pallasite layer. Wood's work was published in 'relatively obscure', unrefereed papers and some reviewers, such as Dodd [8], have not discussed it. But six of the 40-odd known pallasites that have large, rounded olivines (Brenham, Krasnojarsk, Pavlodar, Rawlinna, Springwater and Thiel Mountains) probably formed by buoyancy forces. (Wood [6] incorrectly believed that most pallasites have rounded olivines and suggested that all pallasites formed this way.) Evidence that this is a valid geological process is provided by terrestrial occurrences of net-textured ores consisting of olivine crystals in a matrix of Fe-Ni-Cu sulfides that formed from immiscible sulfide and silicate magmas. Above this analog to the pallastic layer is olivine-rich rock (as in the asteroids) and below it, a layer of Fe-Ni-Cu sulfide (instead of Fe,Ni). The net-textured ores formed as a result of equilibrium buoyancy forces immersing olivine cumulate crystals, which formed in a silicate magma, into a sulfide magma [9]. Thus we conclude that pallasitic layers formed in an analogous way in nearly all asteroids with metal cores.

Angular-olivine pallasites. We have found a polycrystalline, homogeneous olivine mass in Admire, which is 15 cm long and is surrounded by angular olivines of diverse sizes in metal. We infer that the large mass was derived from the overlying olivine mantle, which was composed of olivine crystals typically 0.5-1.5 cm in size with very minor interstitial chromite and possibly traces of Fe,Ni. The crystals appear to have coarsened by grain boundary migration. This is consistent with our observation that rounded olivines seldom exceed 1 cm in diameter whereas pallasites with angular olivines commonly contain olivines 1.5-2 cm in size. All pallasites with angular olivines show metamorphic rounding at high magnifications [4,5]. In addition, we find that some areas of Admire show textures that are virtually identical to those in Brenham except that the rounded olivines are 20-100x smaller and have more diverse sizes. We infer that Brenham-like textures of rounded, coalesced olivines probably formed by grain boundary migration when the raft of olivine cumulate crystals was immersed in molten metal.

Impact mixing of olivine and metal. If as we believe impacts propelled previously molten metal into the fractured olivine mantle, the equilibrium pallasitic layer must have been fractured to allow molten metal to reach the mantle. The textural variety of Brenham specimens is consistent with these proposals: most specimens which can be 50 cm in size, contain uniform rounded olivines in metal. A number of Brenham specimens are entirely composed of Fe,Ni, and a few specimens have regions with both textures [10], commonly a 5-30 cm wide channel of olivine-free metal separates olivine-metal regions. The low Ir concentrations of metal in nearly all main-group pallasites (0.01-0.2 $\mu g/g$) show that the molten metal in both rounded- and angular-olivine pallasites was generally derived from a reservoir that was already 80% fractionally crystallized [11]. In order to prevent metal and olivine from unmixing and angular olivine crystals and Brenham-like pallasitic rafts becoming close-packed, we believe that catastrophic impacts mixed molten metal and then allowed rapid cooling. Rapid cooling at high temperatures would also prevent metamorphic rounding of large angular olivines. Slow cooling at low temperatures [12] implies deep burial after the initial rapid cooling. In this case the catastrophic impact probably occurred before accretion had finished.

The three main group pallasites with angular olivines and high-Ir metal and the high-Ir Pavlodar, which has rounded olivines, may be derived from a separate asteroid. The high-Ir concentrations of metal in the three Eagle Station group pallasites suggest that these pallasites formed by impact mixing prior to core crystallization. We predict that some Eagle Station pallasites will be found with rounded olivines.

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